EXHIBIT 1

Design and Simulation of Two-Stroke Engines

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Cover photo courtesy of Mercury Marine, a Brunswick Company (3.0-liter V-6 outboard engine).

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In this connection the *throttle area ratio*, C_{thr}, is defined as the area of the venturi or the area set by the throttle plate, whichever is the lesser, with respect to the downstream section in Fig. 5.5, as:

$$C_{thr} = \frac{A_{tv}}{A_2} = \frac{d_{tv}^2}{d_2^2} \qquad (5.2.21)$$

At the end of the intake system, adjacent to the airbox, or to the atmosphere if unsilenced as in many racing engines, the diameter is marked as dimension d_4. The input data system to any simulation must be made aware if the geometry there provides a bellmouth end, or is a plain-ended pipe, for Secs. 2.8.2 and 2.8.3 make the point that the pressure wave reflection regime is very dependent on the type of pipe end employed. In other words, the coefficients of discharge of bellmouth and plain-ended pipes are significantly different [5.25].

5.2.4 The exhaust ducting

The exhaust ducting of an engine has a physical geometry that depends on whether the system is tuned to give high specific power output or is simply to provide silencing of the exhaust pressure waves to meet noise and environmental regulations. Even simple systems can be tuned and silenced and, as will be evident in the discussion, the two-stroke engine has the inestimable advantage over its four-stroke counterpart in that the exhaust system should be "choked" at a particular location to provide that tuning to yield a high power output.

Compact untuned exhaust systems for industrial engines

Many industrial engines such as those employed in chainsaws, weed trimmers, or generating sets have space limitations for the entire package, including the exhaust and intake ducting, yet must be well silenced. A typical system is shown sketched in Fig. 5.6. The system has a box silencer, typically some ten or more cylinder volumes in capacity, depending on the aforementioned space limitations. The pipe leading from the exhaust port is usually parallel and has a diameter, d_1, representing area, A_2, in Fig. 2.16, which normally provides a 15-20% increase over the maximum exhaust port area, A_{max}, defined by Eq. 5.2.6. The dimension, d_0, corresponds to the maximum port area, A_{max}. The distribution of box volumes is dictated by silencing and performance considerations, as are the dimensions of the other pipes, dimensioned by lengths and diameter as L_2 and d_2, and L_3 and d_3, respectively.

Tuned exhaust systems for high-performance, single-cylinder engines

Many racing engines, such as those found in motorcycles, snowmobiles and skijets, use the tuned expansion chamber exhaust shown in Fig. 5.7. The dimension, d_0, corresponds to the maximum port area, A_{max}. The pipe leading to dimension, d_1, may be tapered or it can be parallel, depending on the whim of the designer. The first few sections leading to the maximum diameter, d_4, are tapered to give maximum reflective behavior to induce expansion waves, and the remainder of the pipe contracts to reflect the "plugging" pulsations essential for high power output. The empirical design of such a pipe is given in Chapter 6, Sec. 6.2.5. The dimension, d_4, is normally some three times larger than d_1.

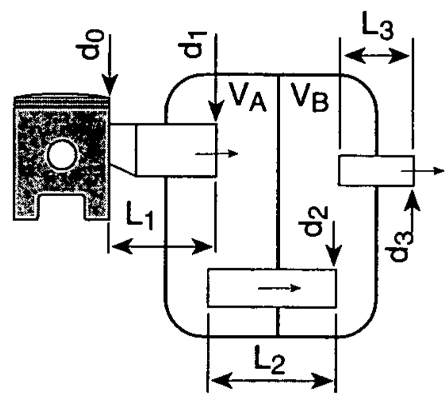

Fig. 5.6 Dimensions of a chainsaw exhaust system.

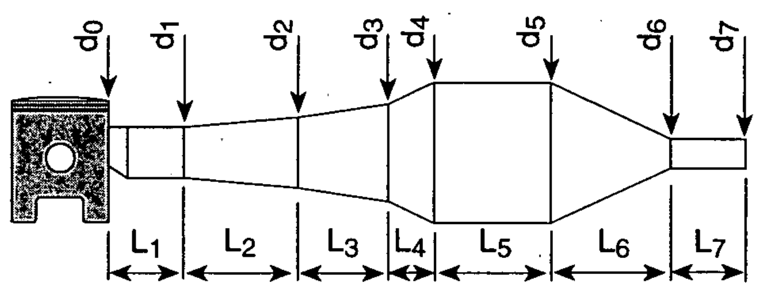

Fig. 5.7 Dimensions of a tuned exhaust system.

The tail-pipe, normally parallel of diameter, d_7, is usually about one-half the diameter of that at d_1. The tail-pipe can lead directly to the atmosphere, but it is extremely noisy as such, vide Plate 5.1. The regulations for motorcycle racing specify a silencer, which is typically a short, straight-through absorption device wrapped around the tail-pipe as seen in Fig. 2.6, the inclusion of which in a simulation is barely noticeable on the ensuing gas dynamics. A discussion on the design of such silencers is found in Chapter 8.

Tuned exhaust systems for high-performance, multi-cylinder engines

Sketches of a typical arrangement of the exhaust manifold and exhaust system of a multi-cylinder two-stroke engine are shown in Figs. 5.8(a) and (b). They are drawn in the context of a three-cylinder engine, but the logical extension of the arrangement to twin-cylinder units and to four or more cylinders is quite evident. It will become clear in the ensuing discussion that the three-cylinder engine has distinct tuning possibilities for the creation of high specific power characteristics which are denied the twin-cylinder and the four-cylinder engine, particularly if they are gasoline-fueled and spark-ignited and have exhaust port timings which open at 100° atdc or earlier. It will also become clear that, if the exhaust port timings are low, as may be the case for a well-designed supercharged engine, then a four-cylinder layout could be the optimum design. The close coupled exhaust manifold of the two-stroke engine will be